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Determination of travertine samples porosity using image analysis method

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ABSTRACT

Natural stones such as Marble, Travertine, and Andesite have been used for construction purposes like exterior coatings, floor coverings etc. for centuries. Knowing the physical and geomechanical properties of these stones beforehand is highly important in view of their proper usage at suitable areas. Porosity, on the other hand, is one of the significant physical rock properties of which determination by means of conventional methods takes too long. In this study, determining rocks' porosity in a fast and reliable manner by using an image analysis method is investigated. The results of the study reveal a direct proportion between the porosity figures obtained by image analysis and by conventional experimental methods, at the coefficient of determination of 0.737 (R^2). This direct proportion is proven to be valid by the use of ANOVA analysis at a confidence interval of 99%.

Keywords: Porosity; Natural stone; Image analysis method.

1. INTRODUCTION

In mining and civil engineering, porosity is an important physical property affecting the geomechanical features of rocks. Since its significance increases day by day, this fact has led many researchers to work on this subject and especially on how porosity could be determined in a fast and reliable manner. So, determination of porosity using image analysis has become a fast, economical and reliable method. Image analysis is a methodology to determine the frequency, shape, rounding and size of grains and the geometry and frequency of porosity (White etal., 1998; Flügel, 2010; Groveand Jerram, 2011; Shi et al., 2015). Digital image analysis is potentially superior in speed and accuracy over point counting. The latest image analysis techniques are proposed by Grove and Jerram (2011) and Wardaya et al. (2013).These technics are very good in making fast and accurate porosity analysis. However, most of the image analysis systems cannot separate and select porosities of different rock types. The development of digital images and of computer software that can perform a variety of image analysis techniques has changed the way that we do modern petrography (e.g., Higgins, 2006; Beggan and Hamilton, 2010). Textures can be digitized and measurements of size, shape, and sorting of constituent grains or crystals can be quickly acquired (e.g., Higgins and Roberge, 2007; Jerram et al., 2009). The quantification of rock porosity can be made by pyknometer test, thin section (e.g., point counting), mercury injection, and helium injection pyknometerand image analysis. Among the traditional methods pyknometer test, thin section require much time and effort. In addition these two methodologies are prone to human error. Mercury injection and helium injection methods are fast but very costly methods. Image analysis on the other hand is both fast and economical. Therefore, digital image analysis is potentially superior in speed and accuracy over other traditional methods.

In this study, the determination of porosity of travertine samples by image analysis is investigated. In this context, the porosity values of these samples obtained both by image analysis and by conventional methods are compared to each other and the relationship between them has been encountered. Linear regression and analysis of variance tools are used to investigate this relationship. By this way reliability of image analysis technique is tested and verified.

2. SYNOPSIS

Nowadays, image analysis methods comprise many procedures such as obtaining, digitizing, enhancing, classifying, saving, and, recalling an image. In particular, these methods can be applied without disrupting an industrial process (Akkoyun, 2010 ; Karakuş, 2007). One of these application areas is the mining sector. Here, image analysis techniques are used in determining the environmental impacts of mines, identification of minerals, prediction of their metal content, approximation of muck piles' size distribution after blasting, etc. (Baykan and Yilmaz, 2010; Cutaia et al., 2004; Kemeny and Handy, 2004; Lane et al., 2008; Latham et al., 2003; Sanchidrian et al., 2006; Yetkin, 2012; Yetkin et al., 2012).

Today, many researchers widely use the image analysis method to analyze and evaluate thin sections of rocks to determine their properties. The analysis of thin sections by scanning electron microscope has become a very popular method for porosity determination.

3. EXPERİMENTAL STUDİES

Porosity of a rock is the proportion of the pores' volume to the total volume of rock and is a dimensionless value (Jumikis, 1979; Nabawy, 2015).

$$n = \frac{V_p}{V_t}, \qquad (1)$$

Where V_p is the total volume of pores, and, V_t is the total volume of rock sample. In sedimentary rocks, porosity varies between the least and the largest values. Typically, it is around 15 % for ordinary sandstone. Moreover, it generally decreases with increasing geological age and formation depth.

Depending on the porosity, physical and geomechanical features of rocks vary. In addition, high rock porosity causes a decrease in uniaxial compressive strength (UCS) and an increase in water absorption rate, affecting directly the quality of rock (Kose and Kahraman, 2014).

Rock porosity can be determined in several ways. According to(Goodman, 1989), the basic techniques given below can be used for porosity determination;

- density measurement

- water content measurement after being water saturated
- mercury content measurement after being mercury saturated with an injector
- solid and pores volume measurement(Boyle's law)
- helium pycnometer usage

In this study, 50 travertine samples are used in experimental studies (Figure 1). These natural stone samples are prepared as cubes (7×7×7 cm), of which all surfaces are scanned at 600 dpi by using commercial flatbed scanner to obtain an image. These images are then saved as a file and examined by using the Digimizer image analysis software (Digimizer, 2005).

Here, for conventional porosity determination, the experiment standards TS 699 (see 'Bibliography') and ISRM 1981, together with equation #2 have been used. Afterwards, density of rock samples is determined by using a helium pycnometer.

$$P = (1 - \frac{dh}{d_0}) \times 100 \qquad (2)$$

where, P is the rock sample's porosity (%), d_h is unit weight of sample (gr/cm^3), and, d_0 is density of sample (gr/cm^3).

Since the pores in the rock do not distribute evenly and homogeneously, in order to obtain the most accurate experiment results, all of 6 surfaces of the cubes are scanned (Figure 1). Steps for the determination of porosity by image analysis are given below;

- transfer of scanned images to software
- entering of sample dimensions to software and enhancement of transferred images
- colouring of pores on image, calculating the pores surfaces and proportioning them to the total sample surface (Equation # 3)

$$PIV(\%) = (a/b)\times 100 \qquad (3)$$

PIV (%): Porosity image value
a:Total of pore surfaces of rock sample (incl. all 6 surfaces)
b:Total of surfaces of rock sample (incl. all 6 surfaces)

Figure 1 Travertine samples used

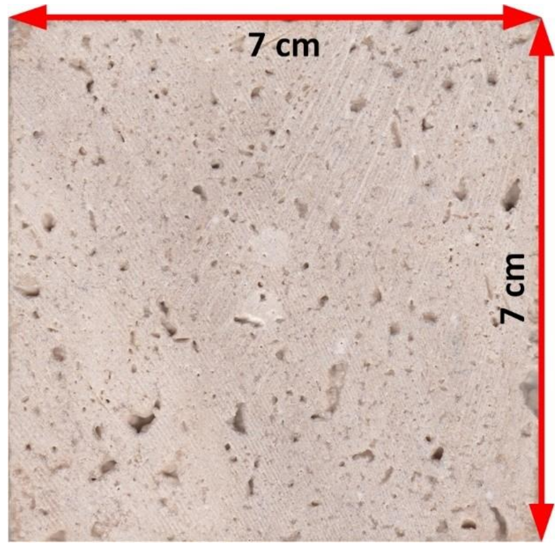

Figure 2 Sample dimensions

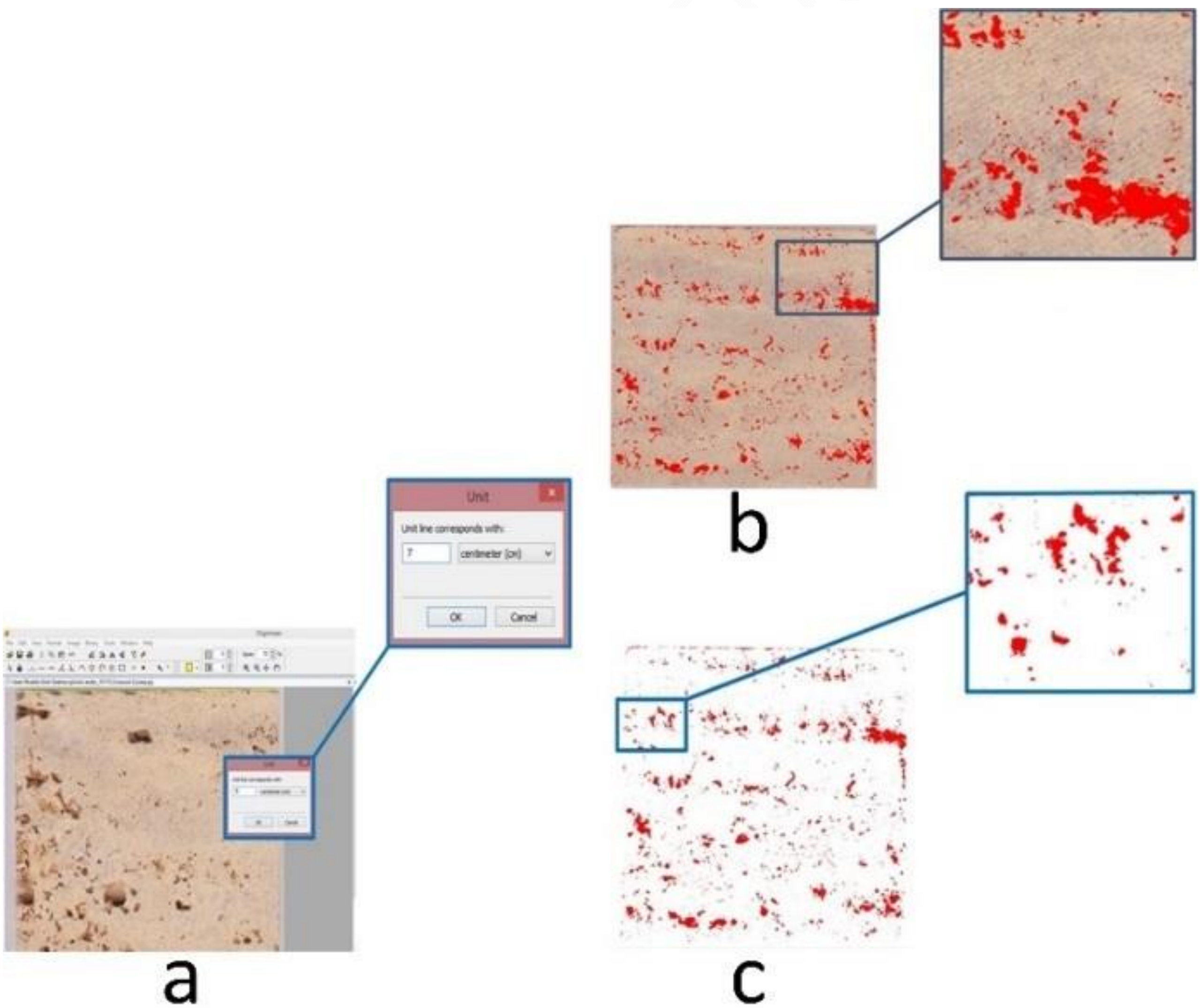

Figure 3 Entering sample dimensions to software and coloring of pores and enhancement process.

Samples used in the study are not subjected to any sanding, grinding or polishing operation. Surface of samples are cleaned using wet wipes. Then surfaces are scanned using a flatbed scanner.This scanner works by digitizing an image surface; dividing it into a grid of boxes and representing each box with either a zero or a one, depending on whether the box is filled in or not. Scanner used in the study has charge-coupled device arrays, which consist of tightly packed rows of light receptors that can detect variations in light intensity and frequency. Resolution quality depends on density of the bit map. The denser the bit map, the higher the resolution. Typically, scanners support resolutions from 72 to 4800 dpi. The numbers of bits are used to represent each pixel. The greater the bit depth, the more colours or greyscales can be represented. Surface image is given in Figure 2. The images taken obtained from the scanner are transmitted to the software for image analysis.

The first operation in image analysis is to input sample dimensions into the software. The dimensions are entered using centimetric scale (Figure 3a). Then the porosities on the samples are colored using "binarization" option of the software (Figure 3b). In the next step, the surface image on the background is removed using "overlay binary image" option and the coloured image of the porosities is left on the screen (Figure 3c). After this step, the area of coloured porosities is computed using "analyze objects" option. Finally, porosity values of samples are found by taking the ratio of total porosity area to the total surface area.

4. DISCUSSION AND EVALUATIONS

Porosity is an important factor on the mechanical behaviour of rocks and rock masses. Porosity affects in pore pressure and permeability in rock mass. Therefore, porosity values are taken into consideration in determining rocks and rock mass properties. Especially, in the mine field works, porosity and other rock properties can be found under mine field conditions. Image analysis method is more advantageous method in this circumstance. Firstly, image analysis experiment takes shorter time compared to conventional methods (Licev at al., 2011). Image analysis operation is rapid, requires lower labour and it is cheaper. Therefore, image analysis is a more advantageous method for rock mechanics laboratory and for the mine projects in the field. On the other hand, image analysis can be applied porous rocks such as travertine. 2D image analysis is based on surface analysis of rocks. Limitation of 2D image analysis is that it does not provide information about the inside content of the rock. Therefore, the real porosity value of the rock is found using pyknometer method and the relationship between the real porosity value and porosity value found by image analysis is investigated. In conclusion, the relationship is found to be very strong which lead us to use image analysis instead of pyknometer. Surely, 3D image analysis is a powerful tool for particle size analysis. 3D analysis of individual particles is the most sophisticated method to obtain quantitative information about the size, shape and arrangement of pores. But, a spherical shaped pores the measured 2D apparent size distribution can be found to a true size distribution by using stereological method. For this reason, 2D image analysis is preferred in the study due to giving similar results with conventional methods.

In this study, porosity values for a number of rock samples are both obtained using conventional methods and using image analysis. These values are given in Table 1. Then the relationships between these two data sets are studied. In conclusion, strong statistical relationship is found between the two data sets. This means, in order to find porosity values of rocks, instead of using conventional methods which are costly and time consuming image analysis can be used which would provide accurate and economical results.

Table 1 Porosity values obtained by conventional methods and by image analysis

Sample Code	Porosity (%) Conventional	Porosity (%) Image Analysis	Sample Code	Porosity (%) Conventional	Porosity (%) Image Analysis
T-1	16.6253	17.0541	**T-26**	14.9654	15.8251
T-2	16.6653	17.7541	**T-27**	14.2511	15.9874
T-3	15.0733	16.9020	**T-28**	15.2827	15.9878
T-4	17.1675	17.4101	**T-29**	15.2010	16.0975
T-5	15.5675	16.2021	**T-30**	14.3050	16.0564
T-6	15.1567	16.1816	**T-31**	15.6755	16.5652
T-7	15.8822	16.5087	**T-32**	16.5452	17.2546
T-8	16.0319	17.0748	**T-33**	17.0209	17.9865
T-9	14.6054	15.3774	**T-34**	17.3024	17.9962
T-10	15.0302	16.3801	**T-35**	15.2454	16.2564

T-11	16.4145	16.8021	**T-36**	15.6213	16.7996
T-12	16.3215	17.7094	**T-37**	16.0400	16.8025
T-13	16.1356	16.5014	**T-38**	15.3141	16.3104
T-14	16.3437	17.3480	**T-39**	16.0622	17.2568
T-15	15.2128	16.7791	**T-40**	16.2329	16.8420
T-16	15.2224	16.4460	**T-41**	16.3798	16.9021
T-17	15.1217	16.2452	**T-42**	15.0382	15.8501
T-18	16.0521	16.5038	**T-43**	15.5147	16.7710
T-19	16.5319	17.0253	**T-44**	14.9585	15.6236
T-20	16.3318	17.1014	**T-45**	16.0274	17.0274
T-21	14.4044	15.3823	**T-46**	16.1102	16.9051
T-22	15.4123	15.8162	**T-47**	16.014	17.0105
T-23	15.8786	16.7072	**T-48**	15.9872	16.8874
T-24	15.4541	16.9546	**T-49**	15.9969	16.5852
T-25	14.7241	15.8808	**T-50**	15.0561	16.2187

While valuating experiment results, the porosity values obtained by conventional methods and by image analysis are compared to each other using statistical evaluation software (Minitab, 2013). Here, 95 % confidence intervals are applied, which is rather a standard value of confidence interval. By evaluating the experiment results in Minitab, it has been found out that the porosity values lie within the 95 % confidence interval at a correlation of 0.737 (R^2) (Figure 4).

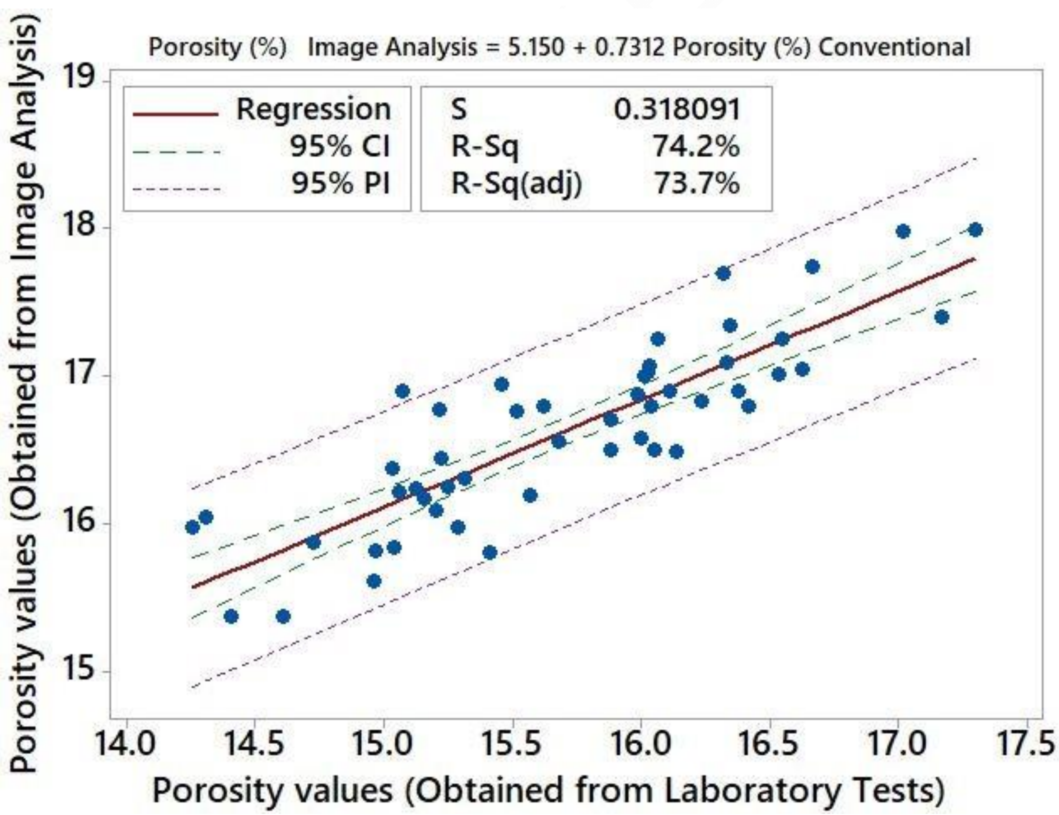

Figure 4 Relationship between porosity values calculated

4.1. ANOVA (Analysis of Variance)

Analysis of variance (ANOVA) is simply an example of the general linear model (GLM) that is commonly used for factorial designs. A factorial design is one in which the experimental conditions can be categorized according to one or more factors, each with two or more levels. The notation used in ANOVA is given below (Winer et al., 1991).

Number of observations in ith sample = n_i, i=1,2, ………. ,k
Total number of observations $=n=\sum_i n_i$
Observation j in ith sample = x_{ij}, j=1,2,………,n_i
Sum of n_i observations in ith sample = $T_i=\sum_j x_{ij}$

Sum of all n observations $=T=\sum_i T_i = \sum_i \sum_j x_{ij}$
Total sum of squares, $SS_T = \sum_i \sum_j x_{ij}^2 - \frac{T^2}{n}$
Sum of squares of regression, $SS_R = \sum_i \frac{T_i^2}{n_i} - \frac{T^2}{n}$
Sum of squared errors, $SS_E = SS_T - SS_B$
Mean squares of regression, $MS_R = \frac{SS_R}{k-1}$
Mean squares of error, $MS_E = \frac{SS_E}{n-k}$
The total degrees of freedom: (k-1) + (n-k)=(n-1)

These formulae are for ***i*** factors. In the case under study there are only two factors considered. So ***k***=2. The general ANOVA table can be seen in Table 2.

Table 2 General ANOVA table

Source	DF	SS	MS	F-Value
Regression	1	SS_R	MS_R	MS_R/MS_E
Error	n-2	SS_E	MS_E	-
Total	n-1	SS_T	-	-

4.2. ANOVA for the Case under Study

For the case under study, ANOVA analysis is carried out on the data. The ANOVA table is given in Table 3 and the residual analysis can be seen in Figure 5. In order to test the validity of regression between the porosity value obtained from image analysis and from the conventional porosity determination, the following null (H_0) and alternative hypothesis (H_1) are developed (Equation# 4). Then, the F test is performed.

H_0: b=0 (4)
H_1: b≠0

Looking at the ANOVA table (Table 3), it can be seen that the F_0 value is found to be 138.04. The confidence level of the test is determined to be 99%. From the F table, the value of $F_{0.01;\,48}$ is found to be 7.08. Since F_0=138.04>7.08= $F_{0.01;\,48}$ H_0 is rejected. This means that "with 99% confidence level, the regression between the porosity values from image analysis and from the conventional porosity determination is valid".

Table 3 ANOVA for the case under study

Source	DF	SS	MS	F-Value
Regression Porosity (%) Image Analysis	1	19.385	19.385	138.04
Error	48	6.741	0.1404	-
Total	49	26.126	-	-

In addition, looking at the residual plots in Figure 5, it can be said that the errors are distributed normally around 0. By the help of many different statistical methods (regression analysis, ANOVA analysis, and residual analysis), the porosity value from image

analysis and from the conventional porosity determination are found to be highly correlated. This shows us that image analysis is a useful and beneficial technique for estimating the porosity value of rock samples.

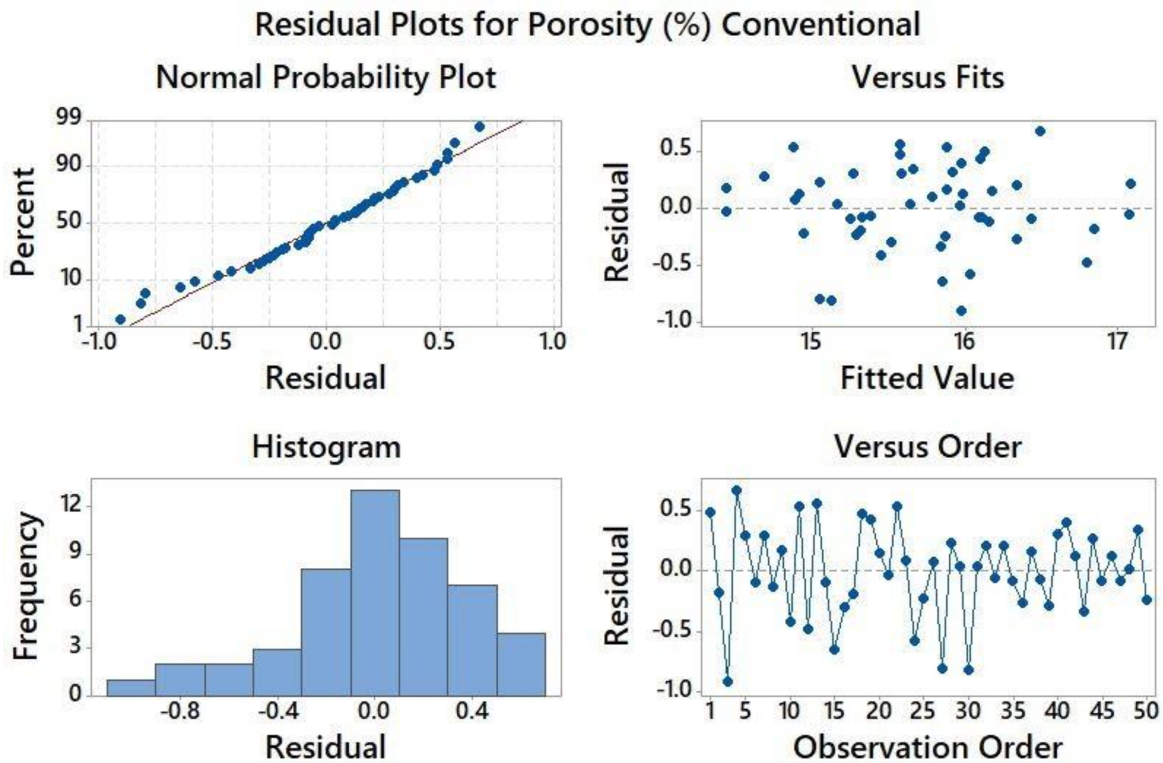

Figure 5 The residual analysis of the porosity values (Minitab, 2013).

5. CONCLUSIONS

By performing this study, it has been seen that for determining physical and geomechanical properties of rocks, image analysis is an alternative method to conventional methods, when extensive laboratory facilities are lacking. The study showed that between the porosity values obtained by conventional methods and by image analysis are in direct proportion at the coefficient of determination of 0.737 (R^2). Besides, the validity of the F-test has been proven by performing an ANOVA analysis.

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